1. Literature Review

The pursuit of sustainable supply chains has driven significant research at the intersection of environmental science, operations management, and computer science. This literature review synthesizes existing research across three key domains:

1. the evolution of carbon footprint measurement and accountability,
2. the application of Artificial Intelligence (AI) in supply chain optimization, and
3. the emerging use of AI specifically for carbon footprint reduction.

The section concludes by identifying the research gap that this study aims to address.

1.1 Foundations of Carbon Footprint Measurement and Accountability

Accurate measurement of greenhouse gas (GHG) emissions is the foundation of any effective carbon reduction strategy. The Greenhouse Gas Protocol (GHGP) established a widely accepted corporate accounting framework by categorizing emissions into three scopes. Scope 1 includes direct emissions from owned or controlled sources, Scope 2 covers indirect emissions from purchased energy, and Scope 3 encompasses all other indirect emissions occurring across the value chain. Among these, Scope 3 emissions are the most difficult to measure due to limited data availability, complex supplier networks, and lack of transparency across multiple tiers.

Life Cycle Assessment (LCA) methodologies provide a comprehensive, product-centric approach by evaluating emissions from raw material extraction through end-of-life stages. However, traditional LCA methods are often static and retrospective, making them unsuitable for real-time or dynamic decision-making in modern supply chains. Recent studies emphasize the need for agile, data-driven carbon accounting systems, highlighting the limitations of manual and spreadsheet-based approaches when applied to complex global supply networks.

1.2 The Rise of AI in Supply Chain Optimization

Artificial Intelligence has emerged as a powerful tool in supply chain management, primarily aimed at improving efficiency, accuracy, and resilience. Machine learning algorithms are widely used for demand forecasting, inventory optimization, and predictive maintenance. Deep learning techniques, such as Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), have further enhanced the ability to analyze complex spatial and temporal data, including traffic patterns and sales trends.

A significant portion of existing literature focuses on AI-driven logistics optimization. Studies demonstrate that AI-based route planning and load optimization can reduce fuel consumption and improve transportation efficiency. Reinforcement Learning is increasingly applied to dynamic scheduling and sequencing problems, enabling real-time decision-making. However, most of these applications prioritize cost reduction, operational efficiency, or service-level improvements.

1.3 AI-Driven Strategies for Explicit Carbon Reduction

A smaller but growing body of research directly addresses carbon footprint reduction using AI. Scholarly work in this area proposes AI-driven frameworks that utilize neural networks and advanced analytics to optimize resource allocation and control emissions across sectors such as energy, transportation, and agriculture. These studies confirm the potential of AI to deliver measurable reductions in carbon emissions when sustainability objectives are explicitly embedded into decision-making models.

Recent research also explores AI-driven carbon footprint optimization in corporate supply chains, identifying applications such as emission hotspot detection, predictive logistics optimization, and sustainable supplier evaluation systems. These approaches position AI not merely as a reporting tool but as an active mechanism for integrating carbon metrics into operational planning.

Additionally, studies highlight the integration of AI with enabling technologies such as the Internet of Things (IoT) and blockchain. IoT sensors enable real-time emission monitoring, while blockchain technology enhances data transparency, traceability, and integrity in carbon reporting.

1.4 Identified Research Gap and Scope of This Study

Despite notable advancements, several gaps remain in the existing literature. Many studies focus primarily on improving supply chain efficiency, with carbon reduction emerging only as an indirect outcome. Others propose conceptual or theoretical AI frameworks without comprehensive validation across multiple supply chain functions. Additionally, much of the research addresses isolated applications—such as transportation routing or inventory management—rather than offering an integrated, end-to-end approach.

There is a clear lack of research presenting a unified, software-centric AI framework that combines predictive analytics, prescriptive multi-objective optimization, and transparent reporting mechanisms specifically designed to reduce Scope 1, Scope 2, and Scope 3 emissions across the entire supply chain.

This study aims to address this gap by proposing an *integrated AI-driven framework that incorporates machine learning, deep learning, and reinforcement learning models for demand prediction and low-carbon operational planning.* The framework emphasizes multi-objective optimization to balance carbon emissions, cost, and service levels, leverages blockchain technology for secure and transparent supplier data management, and employs digital twin simulations for scenario analysis and strategic planning. Through conceptual case studies in manufacturing, logistics, and procurement, this research contributes a practical and actionable architecture for developing carbon-conscious, resilient, and sustainable supply chains aligned with global net-zero goals.